S7-4-6

A STUDY ON PREDICTION AND IMPROVEMENT OF EARLY AGE STRENGTH OF FLY ASH CONCRETE

Shin-ichiro OKAZAKI
Research Associate, Graduate School of Science and Engineering, Ehime University, Japan.

Isao UJIKE
Professor, Graduate School of Science and Engineering, Ehime University, Japan.

Ava KHATRI
Graduate student, Graduate School of Science and Engineering, Ehime University, Japan.

ABSTRACT:
This paper presents a laboratory study on the prediction and improvement of early age strength of fly ash concrete. A study was carried out for the prediction on early age strength of fly ash concrete with different water powder ratios and different curing temperatures by the application of the Goral curve, and for the improvement on early age strength of fly ash concrete. Experimental results have indicated that the Goral curve is applicable for the prediction of early age strength of fly ash concrete in different replacement conditions. And the early age strength improvement of fly ash concrete is possible with the use of rapid hardening Portland cement.
Keywords: fly ash, early age strength, strength growth curve, prediction

1. INTRODUCTION

Fly Ash is a by product of thermal power station which is now a most available supplementary cementing material world wide. In order to considerably increase the utilization of fly ash, some problems on concrete which replaced some of cement by fly ash (here after we call FA concrete) have to be solved. The development of FA concrete strength at early age is one of them. On construction work of concrete structure, the strength of the concrete at early age after casting of concrete is the important quality related to construction process like the determination of removal time of forms and shores. The strength development at early age of FA concrete is slower than that of concrete without fly ash, because the pozzolanic reaction of fly ash is not active at early age. Therefore, it is necessary to predict the early age strength of FA concrete more appropriately and/or to improve that of FA concrete.

Some prediction methods are proposed to evaluate the strength of concrete [1]. However, there is also no prediction method of strength of fly ash concrete corresponding to various replacement ratios. This study investigates the possibility of application of previous prediction method which combines the equivalent age based on the maturity and the strength growth curve by Goral curve [2]. In this study, the evaluation of strength of FA concrete which changed water-powder ratio to three kinds and replacement ratio of fly ash to four kinds is examined. Furthermore, the improvement of early age strength of FA concrete is investigated using rapid hardening Portland cement and various admixtures.

2. EXPERIMENTAL DETALS

2.1 Materials and mix proportions

Ordinary Portland cement [OPC] (density 3.14 g/cm^3) and rapid hardening Portland cement [RHC] (density 3.16 g/cm^3) were used. Crushed sand (density 2.60 g/cm^3) and crushed stone (density 2.60 g/cm^3) were used as fine and coarse aggregate, respectively. Fly ash (density 2.33 g/cm^3) is a product from Tachibana bay thermal power station of Sikoku Electric Power Co.. Air-entraining and water-reducing agency and air-entraining agency were used as chemical admixture. For tests on the improvement of early age strength of FA concrete, following admixtures were chosen with reference to previous studies [3,4,5].

Admixtures which contributes to strength by the reaction of itself : Blast furnace slag, Silica fume

Admixtures which promotes the pozzolanic reaction of fly ash : Slaked lime, Calcium oxide, Calcium carbonate, Sodium hydroxide

Admixtures which promotes the hydration reaction of cement : Calcium sulfate, Gypsum, Sodium sulfate, Magnesium, Lithium carbonate

Concrete specimen was used for the experiment about the prediction of strength. Mortar specimen was used for the experiment about the improvement of strength. The mix proportions of concrete and mortar are shown in Table 1 and Table 2. The value shown in Table 2 is expressed with the amount per one batch.

Table1 Mix proportions of concrete

Type of cement	W/(C+F) (%)	F/(C+F) (%)	s/a (%)	Unit weight (kg/m^3)					Ratio to powder(%)		Slump (cm)	Air (%)
				Water	Cement	Fly ash	Sand	Gravel	WRA	AEA		
OPC	40	0	45	170	425	0	747	924	0.35	0.35	6.0	4.1
		10	45	170	383	42	740	915	0.35	0.45	9.4	4.5
		20	45	167	334	84	740	915	0.35	0.45	6.0	4.1
		30	45	165	289	124	738	912	0.35	0.55	6.3	4.2
	50	0	47	175	350	0	812	932	0.35	0.00	8.0	5.0
		10	47	172	310	34	811	932	0.35	0.25	9.3	4.9
		20	47	172	272	68	809	932	0.35	0.45	9.0	4.4
		30	47	168	235	101	809	930	0.35	0.70	9.5	5.0
	65	0	50	170	262	0	896	907	0.35	0.00	6.0	4.0
		10	50	165	229	25	901	911	0.35	0.25	8.0	4.7
		20	50	170	210	52	887	897	0.35	0.35	12.0	4.2
		30	50	170	183	79	883	893	0.35	0.37	8.0	4.0
RHC	40	20	47	175	350	88	784	870	1.20	0.70	4.5	4.5
	50	20	47	172	275	69	797	910	0.35	0.70	9.4	4.7
	65	20	47	175	215	54	818	951	1.00	0.70	9.0	4.9

Table2 Mix proportions of mortar

W/(C+Ad) (%)	F/(C+F) (%)	powder : sand	Kinds of admixture	Weight per one batch (kg)				
				Water	Cement	Fly ash	Sand	Admixture
50	0	1:2	(OPC)	1.5	3.0	-	6.0	-
50	30	1:2	(OPC＋FA)	1.5	2.1	0.9	6.0	-
50	30	1:2	Blast furnace slag	1.5	2.1	0.6	6.0	0.30
50	30	1:2	Silica fume	1.5	1.95	0.9	5.7	0.15*
51	28	1:2	sodium hydroxide	1.5	2.1	0.8	6.0	0.02
50	25	1:2.2	Slaked lime	1.5	1.8	0.6	6.0	0.30
39	21	1:1.6	Calcium carbonate	1.5	3.0	0.8	6.0	0.02
43	20	1:1.9	Lithium carbonate	1.5	2.7	0.7	6.6	0.06
45	30	1:1.8	Calcium sulfate	1.5	2.1	0.9	5.9	0.30
45	30	1:1.7	Gypsum	1.5	2.1	0.9	5.7	0.30
36	21	1:1.4	Sodium sulfate +slaked lime	1.5	3.0	0.8	6.0	0.26+0.08
51	28	1:2	Magnesium	1.5	2.1	0.8	6.0	0.02

*high-range water-reducing and air-entraining agency

2.2 Specimen and curing

The cylindrical concrete specimens of diameter 10 cm and length 20 cm and cylindrical mortar specimens of diameter 5cm and length 10 cm were prepared. For concrete specimen, sealed curing was carried out in three different water temperatures of 10°c, 20°c and 30°c. The compressive strength of the specimen was tested at the ages of 2, 5, 7, 10, 14, 21 and 28 days from casting. For mortar specimen, curing was done in water temperature of 20°c. Compressive strength test was performed at the ages of 3 and 7days from casting.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 Strength growth curve

Based on the previous research, the early age strength of fly ash concrete was predicted by using the Goral curve [2].

$$f_{c,t} = \frac{a \cdot f_{c,28} \cdot t_m}{b + t_m} \qquad (1)$$

where,

$f_{c,t}$: strength of concrete at age t_m

$f_{c,28}$: strength of concrete at the age of 28 days and at curing temperature of 20°c

t_m : equivalent age based on maturity

a,b : constant

t_m is temperature adjusted age and is calculated by following equation.

$$t_m = \frac{\int_0^t (T - T_0) dt}{T_s - T_0} \qquad (2)$$

where,

T : Curing temperature

T_0 : datum temperature (usually taken to be -10 °C)

T_s : reference temperature (usually taken to be 20 °C)

Constant a and b are related to a type of cement and water-cement ratio (W/C), and is as follows.

$$a = \frac{b+28}{28} \tag{3}$$

Ordinary Portland cement

b=7.55(W/C)-0.10 (4)

Rapid hardening Portland cement

b=5.19(W/C)-0.74 (5)

Portland blast-furnace slag cement, B type

b=16.17(W/C)-2.39 (6)

Low-heat Portland cement

b=94.31(W/C)-25.27 (7)

Constant b for cement containing fly ash partially has been not proposed. It has been reported that the pozzolanic reaction of fly ash is hardly active at early age [6]. Because the purpose of this research is the prediction of early age strength of FA concrete, it is considered that fly ash is an inactive powder like fine aggregate. Therefore, constant b by Eq.(4) is used for the prediction of strength in this study.

3.2 Prediction of early age strength of FA concrete

Fig.1 shows an example of the comparison of measured strength and strength predicted by substantial water-cement ratio and water-powder ratios. For prediction, a measured value is used for concrete strength at the age of 28 days $f_{c,28}$ in Eq.(1). It can be seen from the figure that the measured strength is more close to the strength predicted by substantial water-cement ratio than that by water-powder ratio. It is understood that the prediction is more accurate with the substantial water cement ratio. Hence the prediction is performed by using the substantial water cement ratio and the constants b of ordinary Portland cement.

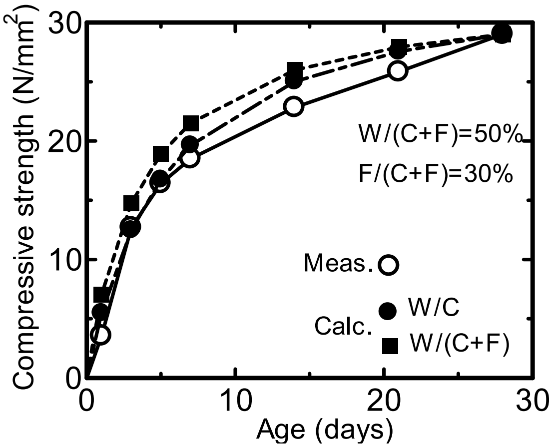

Fig.1 Compressive strength of FA concrete (W/F+C=50%,F/F+C=30%)

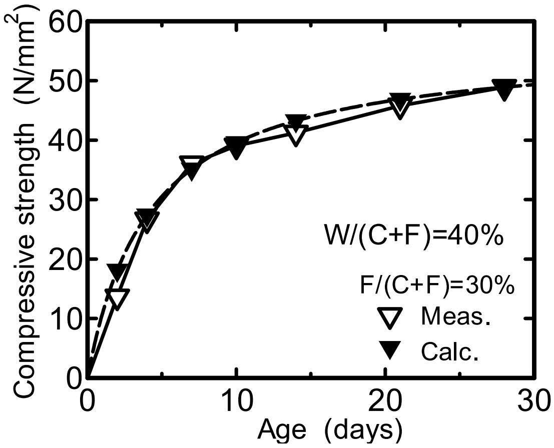

Fig.2 Compressive strength of FA concrete (W/F+C=40%,F/F+C=30%)

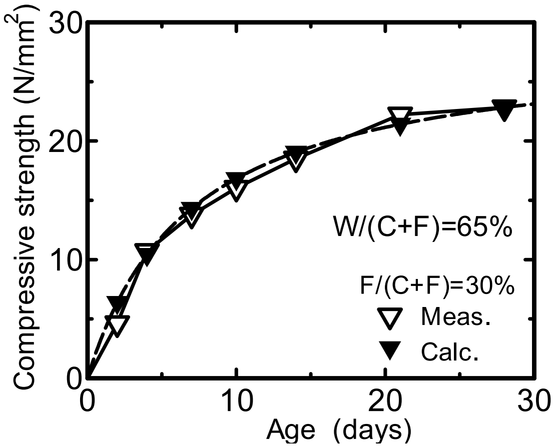

Fig.3 Compressive strength of FA concrete (W/F+C=40%,F/F+C=30%)

The strength prediction of FA concrete is done with different fly ash replacement ratios and water powder ratios 40%, 50% and 65% respectively at curing temperature 20ºc. Fig.2 and Fig.3 show an example of comparison of a measured value and a predicted value. As shown in Fig.2 and Fig.3, the measured values and the prediction values are very close to each other.

Fig.4 shows the comparison of measured strength and predicted strength for all mixing. RMS and SD in figure are root mean squared error and standard deviation, respectively. RMS and SD are calculated by following equations.

$$RMS = \frac{\sum\sqrt{(prediction - measurement)^2}}{measured \cdot number} \tag{8}$$

$$SD = \sqrt{\frac{\sum\left(\frac{prediction - measurement}{measurement}\right)^2}{measured \cdot value}} \tag{9}$$

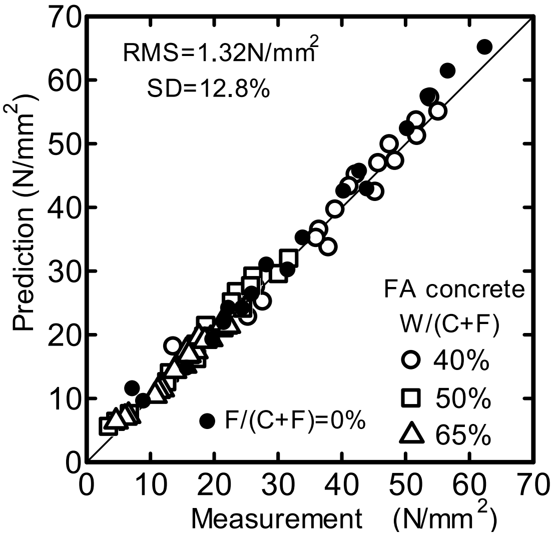

Fig.4 Comparison measured and predicted compressive strength of FA concrete

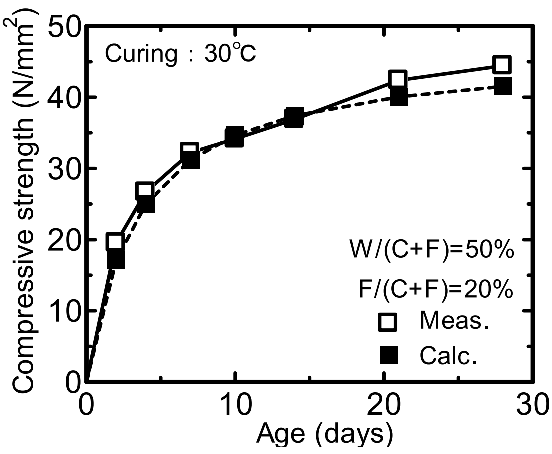

Fig.6 compressive strength of FA concrete cured at 30ºc

From figure, it can be understood that there is accuracy in prediction of early age strength of FA concrete in all mixings. The values of RMS and SD in Fig.4 are calculated from the data about FA concrete. RMS and SD for strength of concrete without fly ash are 1.85 N/mm^2 and 15.0%. RMS and SD for FA concrete are smaller than those for concrete without fly ash. In this study, as substantial water-cement ratio of mixture is used for the prediction of concrete strength, it can predict irrespective of replacement ratio of fly ash.

Fig.5 and Fig.6 show the prediction strength and measured strength of FA concrete at curing temperature of 10ºc and 30ºc. For prediction in Figs.5 and 6, strength at the age of 28 days of concrete cured at temperature of 20ºc is used for $f_{c,\,28}$ in Eq.(1). In the case of curing temperature of 30ºc, it can be seen that the prediction strength is close to the measured strength. And, in the case of curing temperature of 10ºc, a predicted value overestimates a measured value a little. The early age strength of FA concrete cured at different temperatures can be evaluated using Eq.(1) within a certain amount of accuracy.

3.3 Improvements of early age strength of FA concrete

(1) Use of rapid hardening Portland cement

The cause of reduction in early age strength of FA concrete is the decrease of cement content by replacement of fly ash. Therefore, as one of the improving methods, it is considered that the hydration reaction of cement itself is made more active. In this study, rapid hardening Portland cement (RHC) is used to replace the ordinary Portland cement (OPC). Fig.7 and Fig.8 show the compressive strength of FA concrete using RHC. As shown in figures, the strength of FA concrete at early age is improved almost to the same level as the strength of concrete using OPC without fly ash by using RHC.

Furthermore, in Fig.7 and Fig.8, the predicted compressive strength of FA concrete using RHC is shown. The predicted values for FA concrete using RHC is calculated by Eq.(1) and Eq.(5). In this case, substantial water-cement ratio is also substituted for Water-cement ratio in Eq.(5). The early age strength of

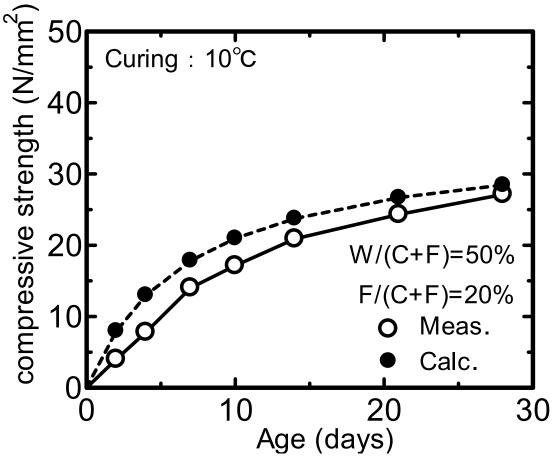

Fig.5 compressive strength of FA concrete cured at 10ºc

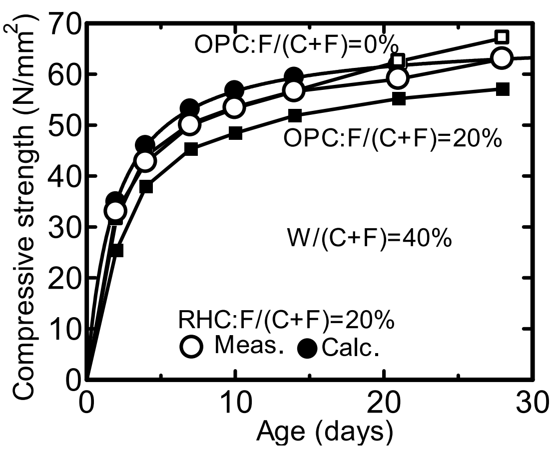

Fig.7 compressive strength of FA concrete using RHC (W/(C+F)=40%)

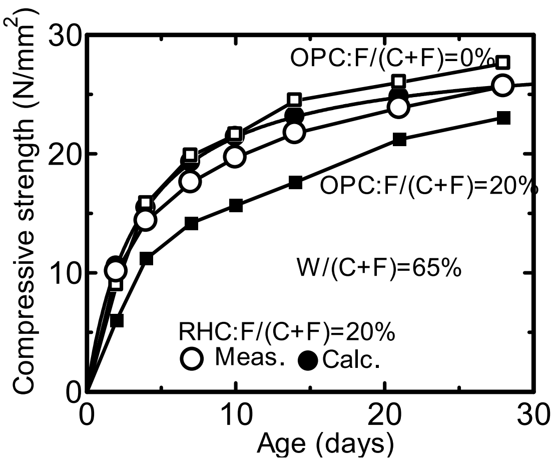

Fig.8 compressive strength of FA concrete using RHC (W/(C+F)=65%)

FA concrete using RHC can be also predicted in good accuracy like that using OPC.

As mentioned above, early age strength of FA concrete is improved by use of RHC. The merit of utilization of fly ash has control of the temperature rise of concrete by hydration heat of cement. However, use of RHC affects the temperature rise of concrete. Fig.9 shows temperature change of mortar. The temperature was measured at center of mortar specimen with 15x15x15cm and mortar specimen is enclosed with thermal insulation with thickness of 20cm. Since the perfect heat insulation state was unreproduceable on this condition, hydration heat of following mortar mixtures was measured on the same conditions, in oder to evaluate relatively.

FA mortar using RHC [W/(C+F)=50%, F/(C+F)=20%]
Mortar using RHC [W/(C+F)=50%, F/(C+F)=0%]
FA mortar using OPC [W/(C+F)=50%, F/(C+F)=20%]
Mortar using OPC [W/(C+F)=50%, F/(C+F)=0%]

The highest temperature of mortar using RHC decreases by about 15ºc by replacement of fly ash. However, the maximum temperature of mortar using RHC with fly ash is high compared with that of mortar using OPC with fly ash. Consequently, temperature behavior of mortar using RHC with fly ash is almost the same as that of mortar using OPC without fly ash.

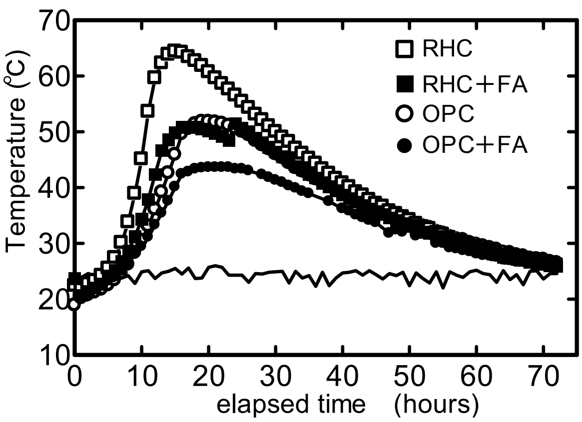

Fig.9 Temperature changes of FA mortar and mortar without FA

(2) Use of admixtures
Mortar test specimens were prepared using different admixtures with the mixing ratios as shown in Table2 and compressive strength was measured at 3 and 7 days from casting. The compressive strength test results are as shown in Fig.10. The admixtures chosen in this study is referring to previous studies and is divided roughly into three as follows. 1) Increase of admixture strength helps to increase the strength of mortar, 2) Make the pozzolanic reaction of fly ash more active, 3) Promote the hydration of cement at early ages.

However, in most of the cases, the early age strength could not be increased, and it is decreased oppositely. As shown in Fig.10, with the addition of lithium carbonate and blast furnace slag, the early age strength is increased by little at age of three days in comparison to that of fly ash mortar, but at age of seven days it could not be increased. With the addition of Na_2SO_4+CaO, the early age strength is increased in both days in comparison to that of fly ash but it is not satisfactory in comparison to strength of mortar using ordinary Portland cement. As one of the reasons why early age strength is not improved by use of admixtures, a difference of the experimental condition between this study and previous studies is considered. This means that admixtures must be used, after checking the validity of the admixture in consideration of mix proportion, materials, construction condition and so on.

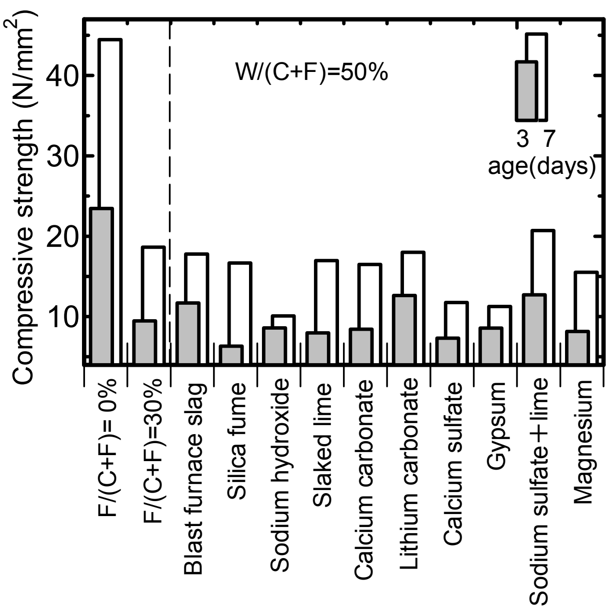

Fig.10 Compressive strength of mortar with admixtures

4. CONCLUSIONS

In this study, to promote the utilization of fly ash as the concrete mixture, the investigation on the strength prediction and the strength improvement of FA concrete at early age are carried out. The results obtained by this research are summarized as follows:

(1) Early age strength of FA concrete with ordinary Portland cement can be predicted with different water powder ratios by the strength growth curve combined Goral curve and maturity.
(2) The early age strength of FA mortar could not be increased with the addition of admixtures.
(3) With the addition of sodium + lime, the early age strength of FA mortar can be increased by a little, but not much satisfactory as compared to concrete without fly ash.
(4) The early age strength of FA concrete can be improved by use of rapid hardening Portland cement and its prediction is also able to be performed in good accuracy.
(5) Although strength of FA concrete can be improved by use of rapid hardening Portland cement, a heat generation characteristic becomes comparable as that of ordinary Portland cement without fly ash.

ACKNOWLEDGEMENT

This research was performed as a part of activity “Subcommittee on research of effective utilization of fly ash “ (Chairman : Professor Ko-ichi Maekawa), Concrete committee, JSCE. The support from the subcommittee is gratefully acknowledged.

REFRENCES

1. Chengiu, G : Maturity of concrete : Method for predicting early-age strength, ACI Materials Journal, Vol.86, No.4, pp.341-353, 1989.4
2. Isao Ujike and Koji Oono : A Study on Prediction of Early-Stage Strength of Concrete Due to Various Growth Curve, JSCE Journal of Materials, Concrete Structures and Pavement, No.798/VI-68, pp.51-61, 2005.9.
3. Qian Jueshi, Shi Caijun, Wang Zhi: Activation of blended cements containing fly ash, Cement and concrete research, Vol.13, Issue 8, pp.1121-1127, 2001.8
4. C.S. Poon, S.C. Kou, L. Lam and Z.S. Lin: Activation of fly ash/ cement systems using calcium sulfate anhydrite, Cement and concrete Research, Vol.31, Issue 6, pp.873-881, 2001.5
5. Gengying Li and Xiaohua Zhao: Properties of concrete incorporating fly ash and ground granulated blast-furnace slag, Cement and Concrete Composites, Vol.25, 3, pp.293-299, 2003.4
6. Takeshi Yamamoto and Tsutomu Kanazu : Experimental explanation of compacting effect on hydration phases and strength development mechanism derived from pozzolanic reaction of fly ash, JSCE Journal of Materials, Concrete Structures and Pavement,Vol.63, No.1, pp.52-65, 2007.1